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*Title:* Shock-wave dispersion in polymeric composites

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*Intended for:* Sandia National Lab

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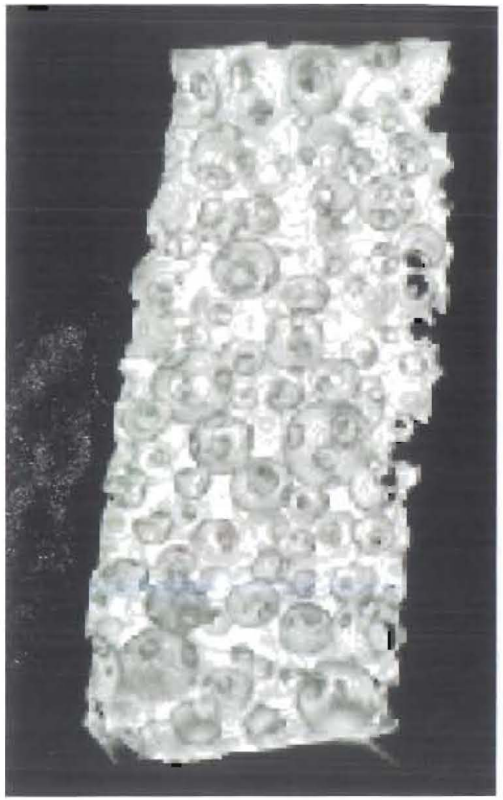
Form 836 (7/06)

# Shock-wave dispersion in polymeric composites

## Proton Radiography Proposal

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Frank Merrill (Co-Investigator)
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# Shock-wave dispersion in polymeric composites

## Abstract

The presentation deals with a LANL proposal to use pRAD to probe the low pressure shock behavior of polymers and polymer composites. The presentation is given to the pRAD review committee, held at LANL on 07/09/09. Per request of the committee members the slides will be disseminated to LANL and SNL personnel. The polymers considered are PMMA, PDMS, and graphite-epoxy.


Dana Dattelbaum, Brad Clements, Frank Merrill

# Shock-wave dispersion in polymeric composites

Goal: Apply proton radiography as a diagnostic of shock wave evolution in programmatically-relevant complex, multi-phase polymers loaded under large dynamic compressions.

Objectives:

1. To evaluate prad as a diagnostic of shocked density in low Z materials
2. To apply prad to examine pore collapse and its influence on shock front dispersion in polymeric foams
3. To interrogate the complex shock wave interactions associated with dynamic compression and subsequent failure (spallation) through a filled composite containing both high and low strength materials and void content.

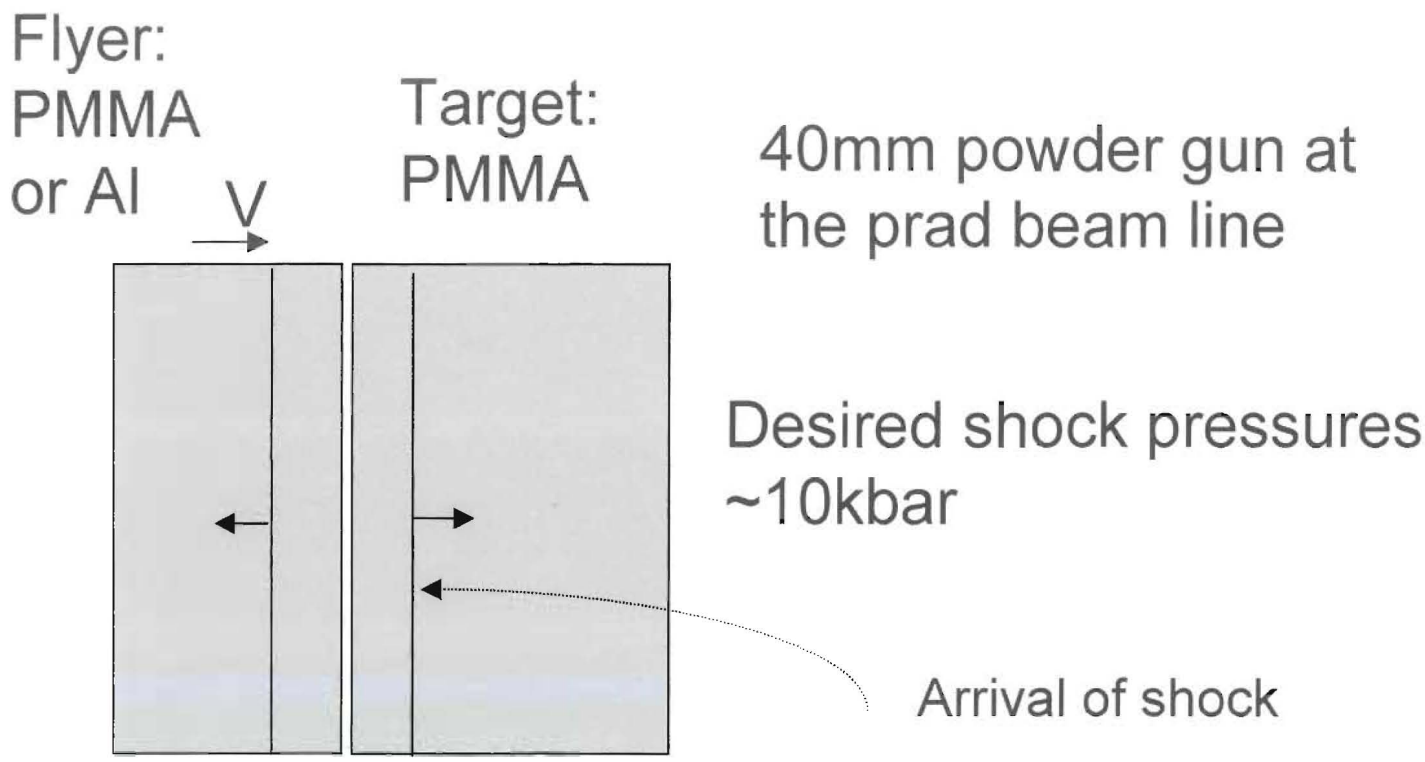

Dana Dattelbaum, Brad Clements, Frank Merrill

# Shock-wave dispersion in polymeric composites

Proposed experiment 1: Direct density measurements in low Z (and density) materials.

The goal is to use proton radiography on a prototypical polymeric material (polymethylmethacrylate (PMMA)), having a well-known equation of state, to evaluate its capability for direct density measurements in a low Z material.

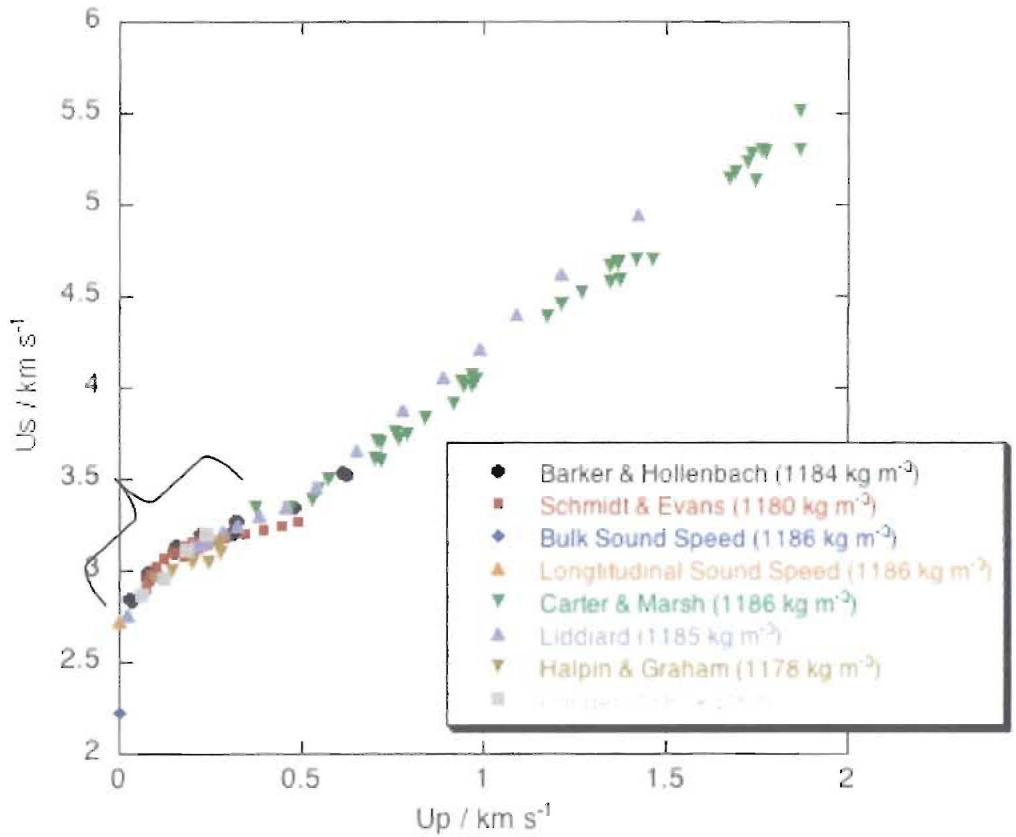
# Proposed experiment 1: Direct density measurements…




Below 10kbar viscoelastic effects are clearly evident in PMMA. It would be extremely interesting to observe these effects using prad.

# Proposed experiment 1: Direct density measurements…

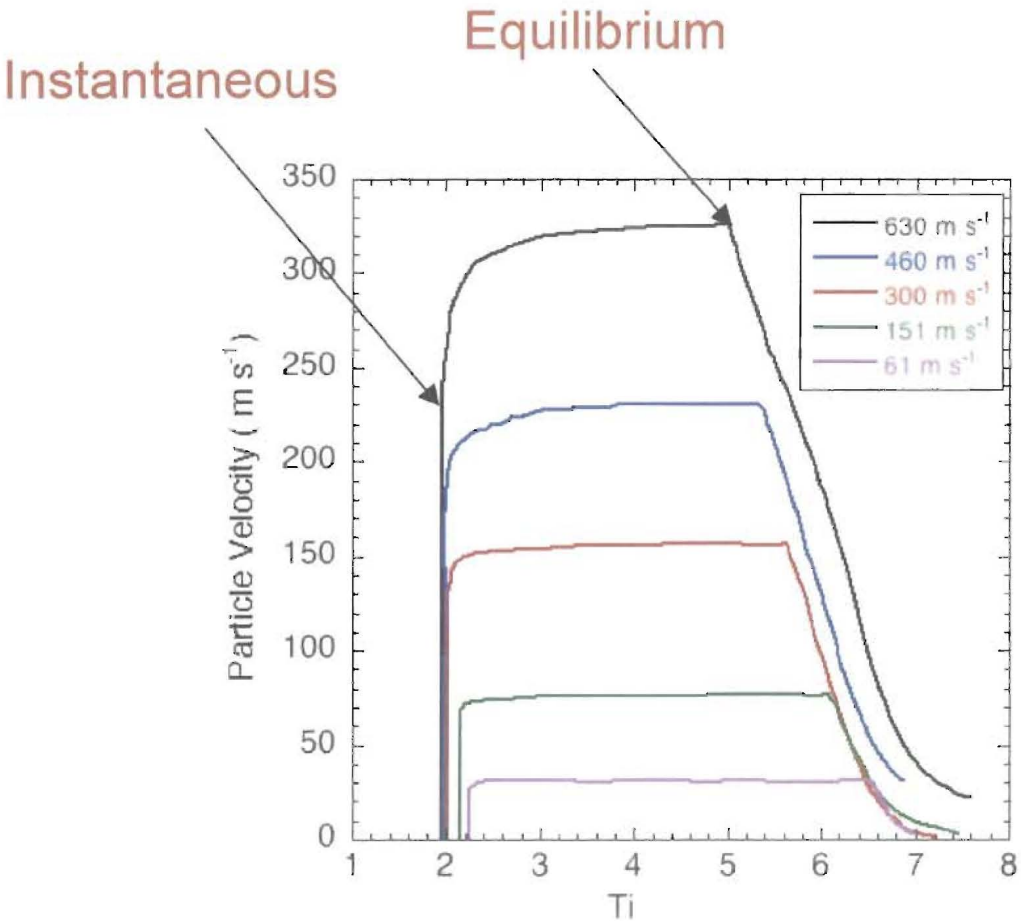
## Why PMMA: PMMA has a well known Hugoniot EOS




Density = 1.189 g/cc

# Proposed experiment 1: Direct density measurements…

## Viscoelasticity is apparent from shock experiments




Symmetric Impact of PMMA

Barker and Hollenbach, 1970
Schuler, 1970 etc
Nunziato et al. 1973, etc.

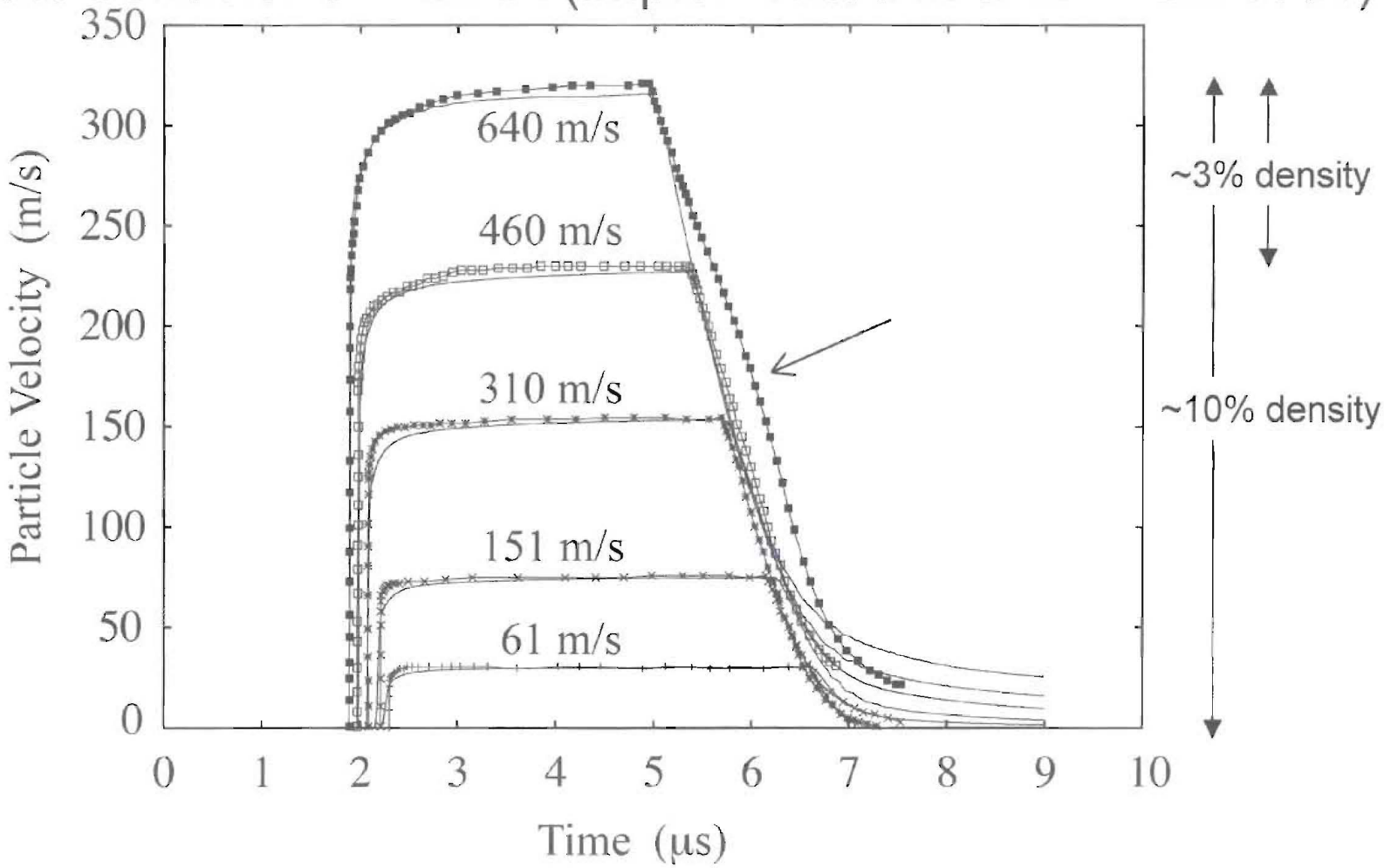
⋮

Bourne, Millet and Gray
Dattelbaum (other polymers)
etc.

Uniaxial strain shock experiment, rates ~$10^6$ 1/s

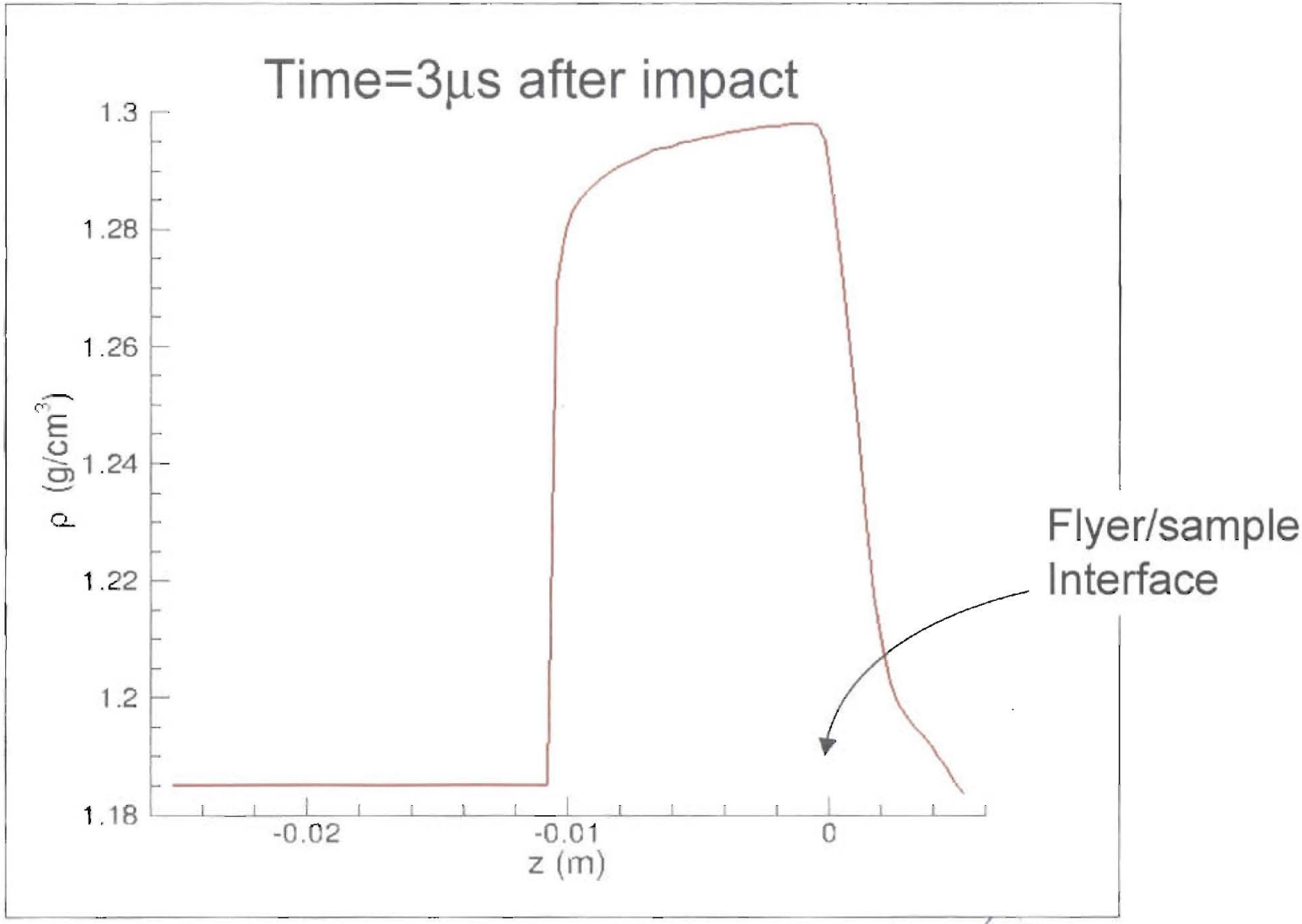
# Proposed experiment 1: Direct density measurements…

Furthermore: the constitutive theory of Clements accurately models the behavior of PMMA (implemented in a 2D FEM code)



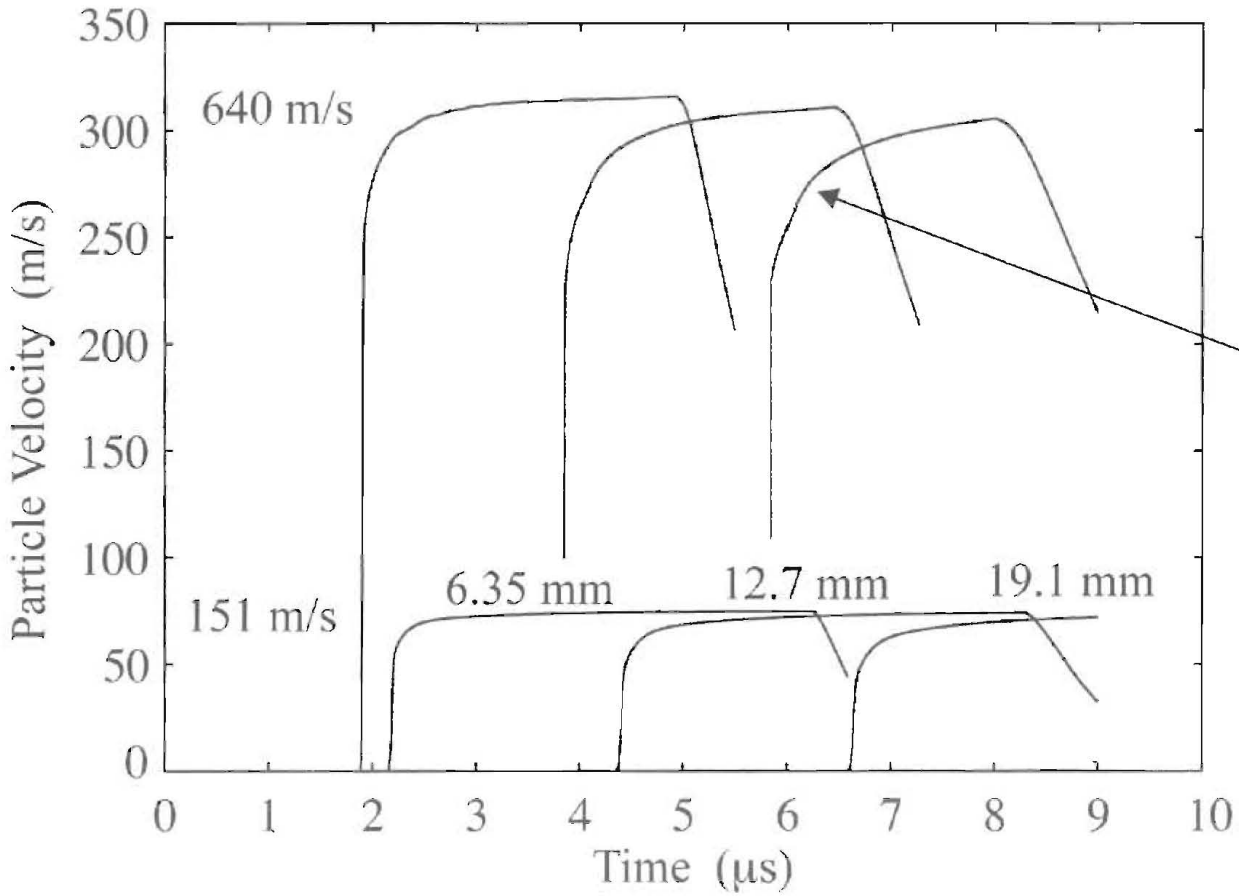

Barker and Hollenbach: 6.35mm PMMA striking 6.35 mm PMMA

# Proposed experiment 1: Direct density measurements…



# Proposed experiment 1: Direct density measurements…

Relaxation behavior is consistent with shock experiments. Can the spreading of the transition zone be observed in prad?




For high velocity shots there is a noticeable spreading of the transition zone (agrees with Schuler)

Less rounding observed at low impacts

# Proposed experiment 2: Measurement of shock dispersion in PDMS-based foams…

Silica-filled PDMS foams are used widely in the DOE complex.

$(C_2H_6OSi)_n$

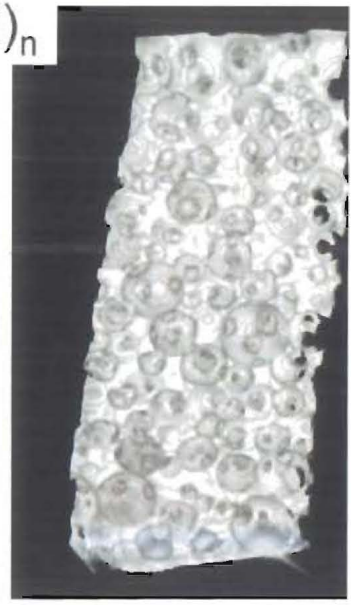


Fig. 1. PDMS foam microstructures from x-ray microtomography. Image is reconstructure of S5370 foam part from radiographs.

Radiographs from Brian Patterson, MST-7.

- Open celled, with pore sizes 50-200μm, and holes between pores
- DOE/NNSA Campaign 2 in FY-08 study the influence of pore size and distribution on the mechanical properties of the foam
- Using same techniques for controlling pore size and distribution, we propose to use prad as a diagnostic of dynamic compression behavior.
- Under shock compression of foams, huge shock heating occurs: 100kbar shock in polyurethane foam produces temperatures near 3000K - getting the physics correct is important.

# Proposed experiment 2: Measurement of shock dispersion in PDMS-based foams…

- We propose to shock compress 6mm thick foams that have large size pores (~750μm) and use prad to interrogate shock front dispersion as the shock compacts the foam.

- prad is an excellent technique for examining the smoothness of the wave because of its spatial resolution (150μm) with a temporal resolution on the order of hundreds of nanoseconds.

- Crucial to testing our hypothesis that bulk shock experiments are accurate (traditionally VISAR or in-material gauges).

- While large pores may be resolvable in static prad shots, it is not necessary to resolve them dynamically, only the effects of dynamic compaction and density variations need to be resolvable.

# Proposed experiment 2: Measurement of shock dispersion in PDMS-based foams…

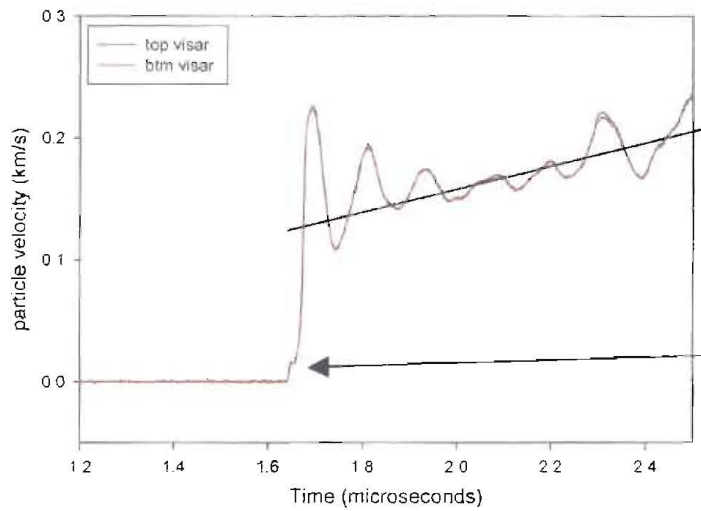



**Fig. 2** VISAR wave profiles from a shock reverberation experiment in which low density SX358 PDMS foam has been impacted into a LiF window. The VISAR measurement is at the foam-LiF interface. There is evidence of ramped behavior in the shock rise, and a low amplitude precursor

Previous shock studies on a low density foam, using VISAR, exhibited a ramp shape, and a low amplitude precursor.

We hope to observe and better understand these effects using prad.

# Proposed experiment 3: Complex shock wave interactions in graphite-epoxy composites

Developing a constitutive model for graphite-epoxy is of high relevance to the DOE and the DoD

Voids

Small and large diameter rocket case material

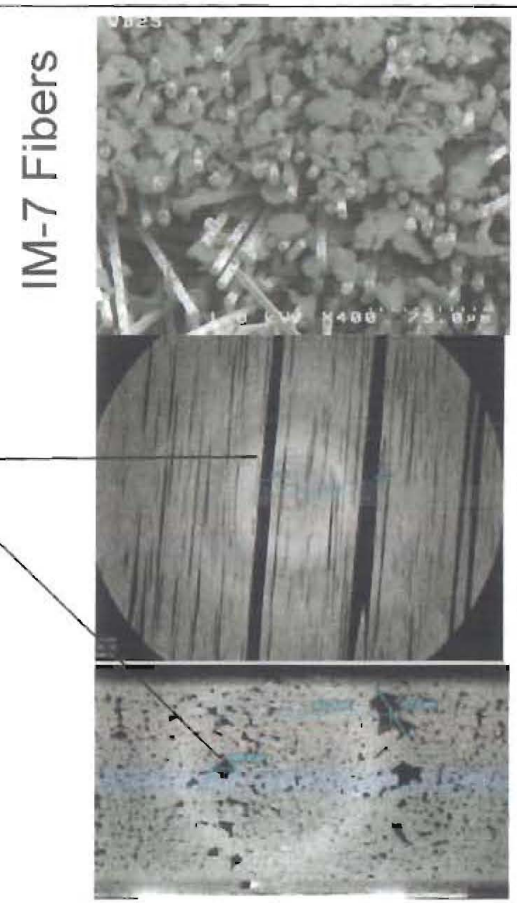



**Fig. 3** Radiographs of a graphite-epoxy rocket case material. The composite consists of ~ 5 micron diameter IM-7 fibers contained in an epoxy matrix (top). There is significant void content in the composite as shown in the top down and end on views (middle and bottom), with the voids running in one direction through the material at 60-800 micron diameter.

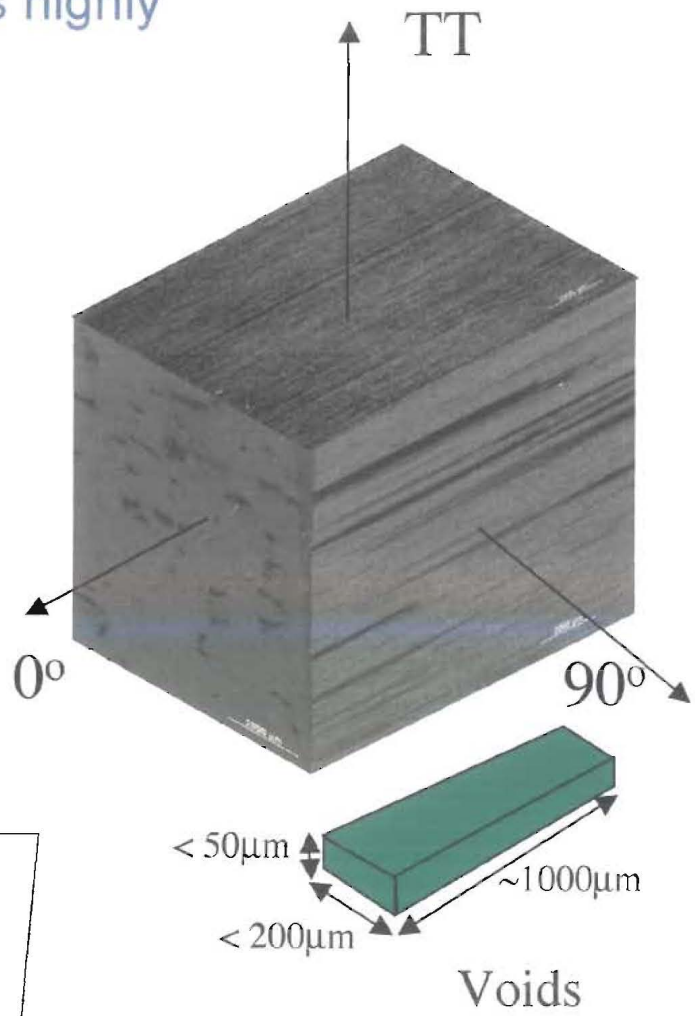
The Joint Munitions Program (JMP) has made considerable investment in this area (both experiment and theory), especially for fragment-impact studies.

# Proposed experiment 3: Complex shock wave interactions in graphite-epoxy composites

Understanding damage is critical, and damage is highly influenced by the void structure.

## Panel Manufacturing Process

- **IM7 fiber bundles are wet wound onto a large diameter mandrel at ~90° (hoop) and are allowed to partially cure.**
- **The composite cylinder is cut along the axis and flattened to form unidirectional B-staged laminate.**
- **Several laminates are stacked and condensed in a hot press to form unidirectional panels of three thicknesses.**
- **This closely mimics the resulting composite casing microstructures.**
- **The resulting process results in high porosity with pores <50μm in the TT direction, <200μm perp. to the fiber direction, and ~mm in the fiber direction.**

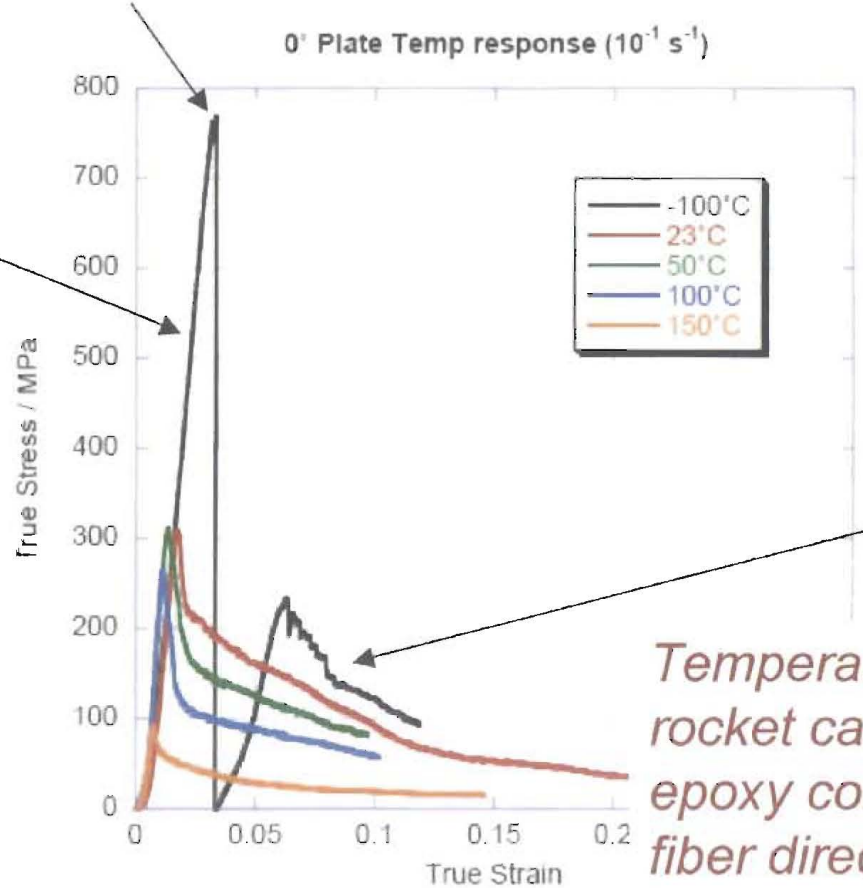


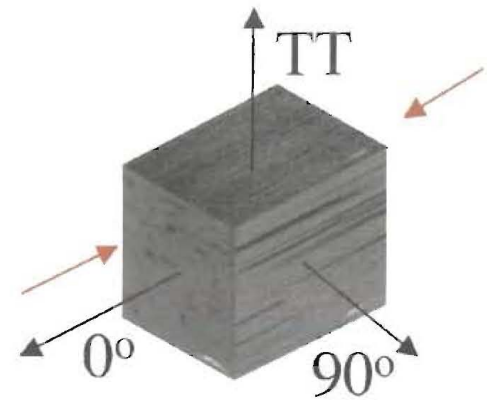
# Proposed experiment 3: Complex shock wave interactions in graphite-epoxy composites

We have investigated the mechanical properties of the epoxy resin and the composite in detail at low rates of deformation …

Fibers buckle and break catastrophically

Dominated By fiber



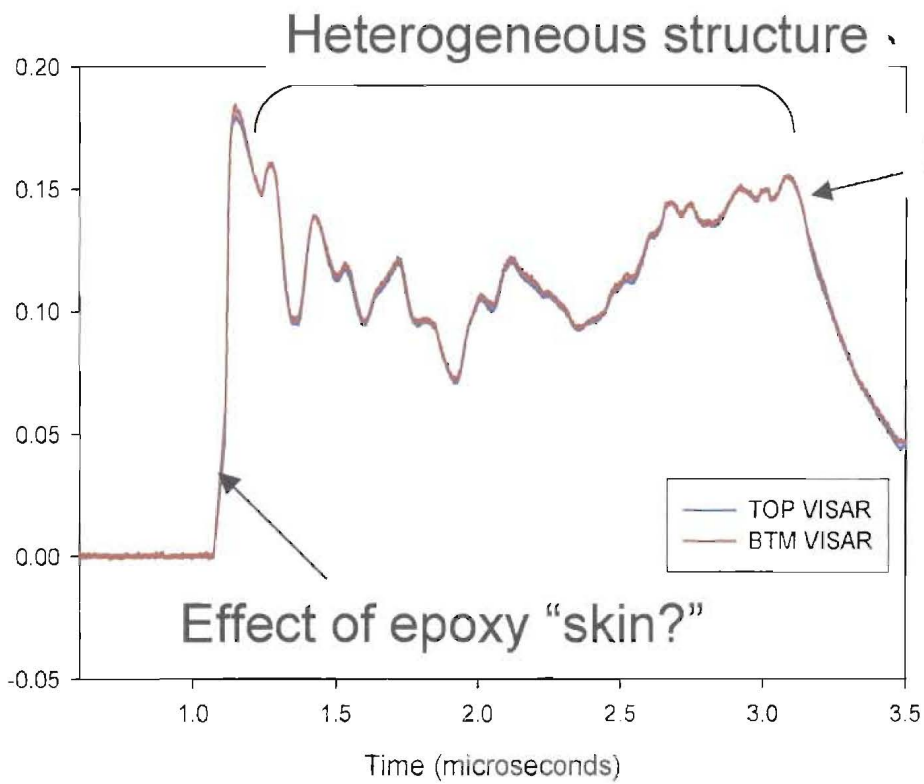

Response has an epoxy part upon reload

*Temperature dependence of the rocket case graphite epoxy composite in the aligned fiber direction is dominated by the fibers*

# Proposed experiment 3: Complex shock wave interactions in graphite-epoxy composites

and at shock rates….

Dattelbaum, Rae, Brown, Orler, Gustavsen, Sheffield, and Patterson



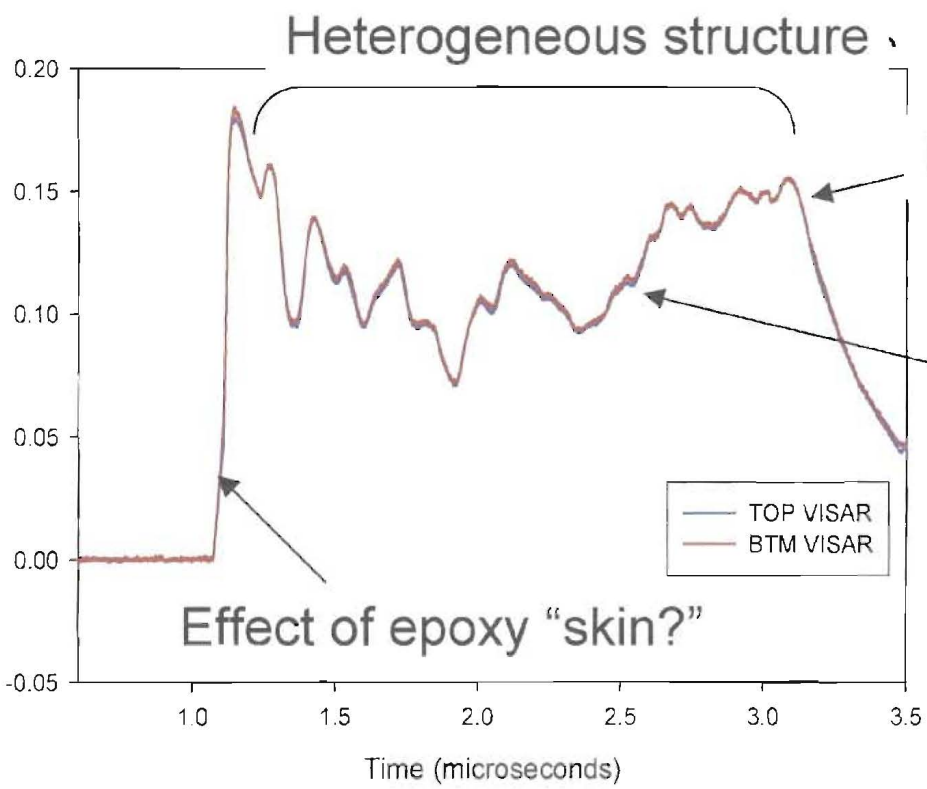

We have performed 3 front surface impact exp'ts on the 90° direction.

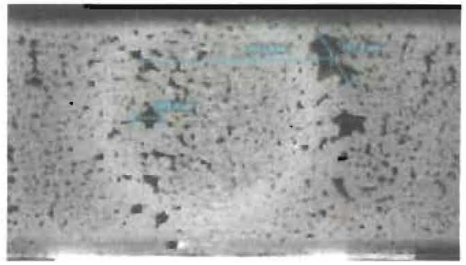
We have also performed shots on epoxy 55A resin

$$U_s = 2.634 + 1.587u_p$$

# Proposed experiment 3: Complex shock wave interactions in graphite-epoxy composites

The unique unidirectional lay-up of the void structure in this composite offers a compelling opportunity to interrogate dynamic pore collapse using prad without the complicating features of a 2 or 3D porous material.



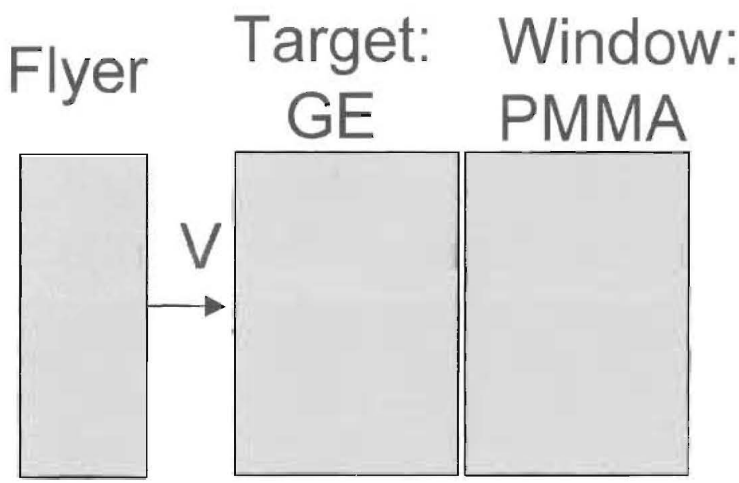



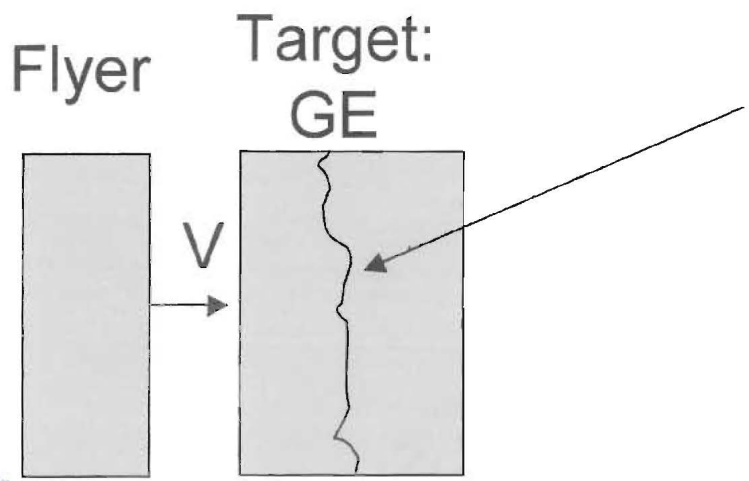
From knowledge gained by the traditional VISAR experiments we anticipate the wave shape will be highly complex.

Using prad, can we gain insights in the causes of this behavior, *i.e.*, we propose to study the shock evolution and dispersion.

# Proposed experiment 3: Complex shock wave interactions in graphite-epoxy composites

Two experimental setups:




To study dynamic fracture, *i.e.*, spall

# Big Picture stuff…

***Motivation 1:*** There are many DOE/DoD polymers of interest that have important roles:

HE Science, ASC

Crucial to Survivability in an STS Environment

- as HE Binders and Reactive Materials
- as Structural Components (Padding, Cushions, Struts)
- as Rocket, Missile Cases, & Aeroshells
- as Light Weight Armor

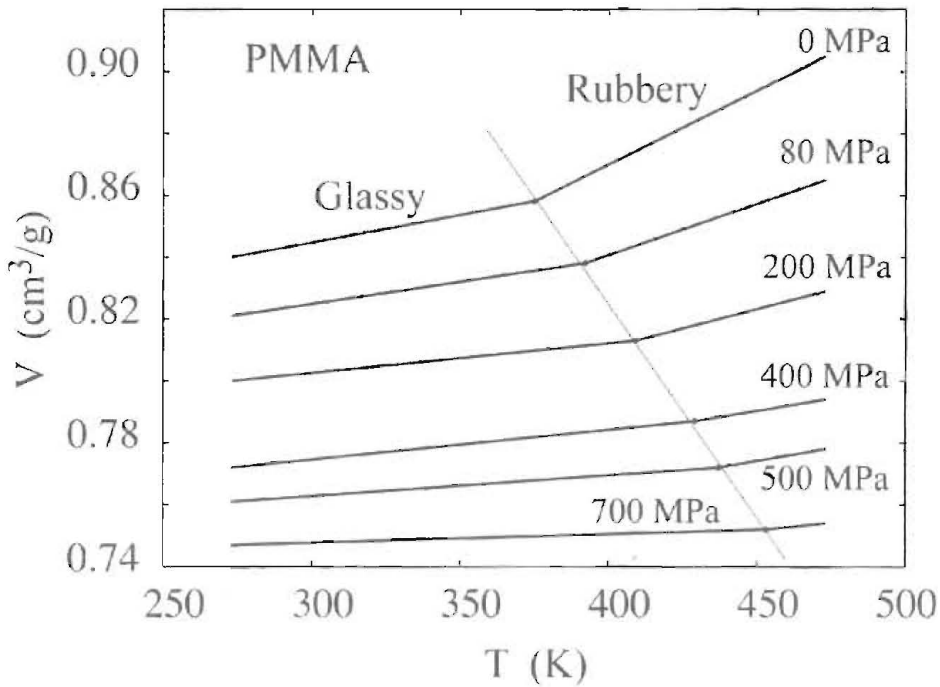
Safety & Surety Programs

***Motivation 2:*** Many codes, such as the ASC and DoD codes, are now demanding better, more predictive material constitutive models for the polymers that occur in weapons.

***Yet***, the models currently used by the DOE/DoD are typically *based on metals physics*. Consequently, there is a great need from both the DOE and DoD to improve our modeling capability of polymers and polymer composites.

# In conclusion …

We need new and better techniques to push forward on unraveling the complex behavior of polymers and polymer composites. This proposal provides proton radiography with an opportunity to test itself as a truly important research tool for these materials. While clearly successful for metals and explosives, success in this area will open up a broad range of possibilities.




Volume change at the glass transition in PMMA.